

Integration of Total Productive Maintenance and Industry 4.0 to increase the productivity of NC Bore machines in the Musical Instrument Industry

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Abstract

Improper maintenance and repair of machines can cause decreased productivity and machine effectiveness. The Musical Instrument Industry is a manufacturing industry that is engaged in manufacturing musical instruments such as the piano. In the production process, many wood machines are used, such as the NC Bore Machine. Machines that operate continuously are required to meet the targets that have been set with a high level of effectiveness. The problems in the production process are that there are a lot of breakdowns that occur in NC Bore machines and a less than an optimal amount of production which results in a lack of the total machine effectiveness index (OEE). To increase productivity, Total Productive Maintenance (TPM) is implemented by analysis Overall Equipment Effectiveness (OEE). This research aims to increase the productivity of NC Bore machines. This research resulted in an OEE score of 87%, 94% machine availability, 93% performance rate, and 99% quality rate. This value meets world-class standards.

Keywords - TPM, OEE, Industry 4.0, NC Bore, productivity.

1. Introduction

Nowadays, industrial development in all fields, both the goods and services industry, is increasing rapidly, causing intense competition between companies in the global market. In competition in the global market, a business strategy is needed to win the competition, because this is one of the competitive advantages. Currently, the company is faced with the problem of high productivity, both the productivity of human resources and the productivity of production machines. The business strategy to achieve competitive advantage is the success in maintaining or maintaining a machine so that engine performance remains reliable and maintained.

The Musical Instrument Industry is an industry that is engaged in manufacturing musical instruments, one of which is piano production. The Musical Instrument Industry is a company that implements machine maintenance based on the service life of each engine component. NC Bore machines in the Musical Instrument Industry are generally machines used to bore holes in some parts of the piano body. This process is carried out at Wood Working, which is the process of forming parts from wood-based materials. Figure 1 shows the level of damage to machines in the Wood Working process, one of which is the NC Bore Machine. During the last three years, the most breakdown to NC Bore machines and continues to increase, this needs to be repaired so that in the future it does not harm the company.

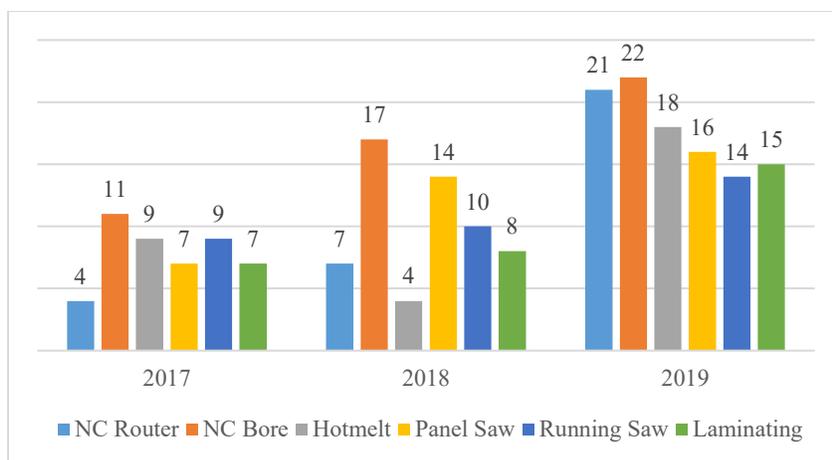


Figure 1. Machine breakdown data in wood working process 2017-2019 (hour)

To increase productivity on these machines, a maintenance method is used namely Total Productive Maintenance, with the calculation of the OEE value as a parameter. TPM is present as an approach to make it happen. TPM is an approach introduced by Nakajima in 1988. This approach was developed as a strategy for maintaining and improving engine performance. TPM through OEE is also to measure the productivity of equipment or machines in various industrial sectors (Sultoni & Suroso, 2019; Perdana, 2018).

In line with that, the implementation of TPM is very important to achieve a reduction in production costs and increase product value. The company has implemented TPM to minimize production costs due to losses incurred in the company. Losses that occur can be caused by various factors, including operator, maintenance, process, equipment and unavailability of spare parts (Singh et al., 2013). Other losses can also be caused by engine breakdown, which has led many companies in the world to apply the TPM method as a method of maintaining their machines. So that the machine is always in a ready-to-use condition, it is necessary to carry out planned care and maintenance. By carrying out maintenance and maintenance, it can increase the productivity and efficiency of the machine, so that losses caused by machine breakdown can be avoided. Along with adjusting to increasingly modern technological developments, the implementation of TPM must also be balanced with current conditions such as the application of several characteristics of industry 4.0 (Bekar et al., 2019).

OEE is a very important measure for the implementation of a strategy to increase TPM. This study aims to bring OEE closer to 85% and gradually move towards world-class manufacturing (LEVITT). TPM uses OEE as a quantitative parameter to measure the performance of a production system and is a core metric for measuring the success of a TPM implementation program. Today, TPM is one of the most popular engine performance enhancement innovations in various industrial sectors, including the manufacturing industry. Many studies claim that TPM is the right method for increasing machine productivity and effectiveness. When implemented in the automotive manufacturing industry, TPM through OEE can help the relationship between the maintenance and production departments (Rozak et al., 2020). TPM can overcome equipment/machine failures so that it can reduce production rates as well as product quality (Purba et al., 2018) (Morales Méndez & Rodríguez, 2017). Besides manufacturing, TPM can also be applied in medical equipment (Haddad & Jaaron, 2012) (Chompu-Inwai et al., 2008). The application of TPM in the laboratory service industry, TPM can increase machine performance which is influenced by performance levels (Nurcahyo et al., 2018). TPM in any organization improves OEE by increasing equipment availability and reducing the number of rejects and reworks (Wakjira & Singh, 2013).

The overall productivity of an industry can also be increased by implementing TPM. The implementation of TPM creates beneficial changes in operator attitudes, encourages a clean and attractive workplace and also increases the level of employee confidence and job satisfaction (Jain et al., 2014). The application of TPM not only increases the OEE of large industries but also improves the OEE of small industries by increasing the availability, performance and quality level of machines (Prashanth Pai et al., 2018) (Nallusamy, 2016).

This research aims to increase the productivity of NC Bore machines. Referring to the implementation of Total Productive Maintenance in manufacturing companies, especially in the woodworking process (Apriatno, 2015), the Musical Instrument Industry is expected to bring companies to world-class performance and machine reliability (Ljungberg, 1998). Thus the application of TPM will increase the value of OEE so that the company will be able to increase its productivity.

2. Literature Review

2.1. Total Productive Maintenance

TPM began to be developed in 1970 at companies in Japan which were the developers of the maintenance concept applied to the United States manufacturing industrial company called preventive maintenance. TPM is a program concept on maintenance that involves all workers through small group activities. When implementing TPM, the production and maintenance units must work together. Its application will involve all employees in maintaining machinery and equipment and aims to increase productivity (Dogra et al., 2011). The TPM strategy has many benefits including keeping the work environment clean, zero accidents, increasing operator involvement, improving product quality, reducing costs, focusing on maintenance techniques, increasing problem solving by the team and certainly improving machine or equipment performance (Vigneshwaran et al., 2015)

The indicator of success in implementing TPM is measured by OEE and the parameters include various types of losses which we know as six big losses (Denso, 2006). OEE is a calculation that is carried out to determine the extent of the effectiveness of an existing machine or equipment. So that it can be seen the availability, production efficiency, and the quality of the output of the machine or equipment. OEE can be calculated by the formula:

$$\text{OEE} = \text{Availability} \times \text{Performance} \times \text{Quality} \quad (1)$$

There are three elements of productivity and effectiveness of equipment or machines that can be measured, namely availability, performance and quality.

Availability is a measure of the extent to which the machine can function. Availability is the ratio of operating time to preparation time.

$$\text{Availability} = \frac{(\text{Loading Time} - \text{Unplanned Downtime})}{\text{Loading Time}} \times 100\% \quad (2)$$

Performance is the ratio of the quantity of the product produced multiplied by the ideal cycle time to the time available to carry out the production process.

$$\text{Performance} = \frac{(\text{Idle Run Time} \times \text{Total Production Part})}{\text{Operating Time}} \times 100\% \quad (3)$$

Quality is the ratio of the number of good products to the total product in the process

$$\text{Quality} = \frac{(\text{Total Produced Parts} - \text{Total Defect Parts})}{\text{Total Produced Parts}} \times 100\% \quad (4)$$

The OEE value is a parameter of success in implementing TPM (Ljungberg, 1998). The OEE value has three elements that can be measured, namely the 90% availability level, 95% performance level, and 99% quality level. These three elements, when combined, are known as OEE. The world-class benchmark standard recommended by the Japan Institute of Plant Maintenance (JIPM) is 85%. The OEE value of 85% can be said that this performance is world-class performance (Nakajima, 1988)

2.2. Six Big Losses

According to (Nakajima, 1988), the purpose of calculating six big losses is to determine the overall effectiveness value of the equipment/machine. From this OEE value, steps are taken to improve and maintain this value. The six losses can be classified into three types, namely:

1. Availability: Downtime losses, consisting of (a) Breakdown losses/equipment failures (b) Setup and adjustment losses
2. Performance: Speed loss, consisting of (a) Idling and minor stoppage losses (b) Reduced speed losses
3. Quality: Defect loss, consisting of (a) Process defect (b) Reduced yield/scrap

To apply the TPM concept in a manufacturing company, a strong foundation and strong pillars are needed. The foundation of TPM is 5S, while the main pillar of TPM consists of 8 pillars. The eight pillars of TPM are mostly focused on proactive and preventive techniques to increase the reliability of production machines and equipment. The eight pillars can be seen in Figure 2.

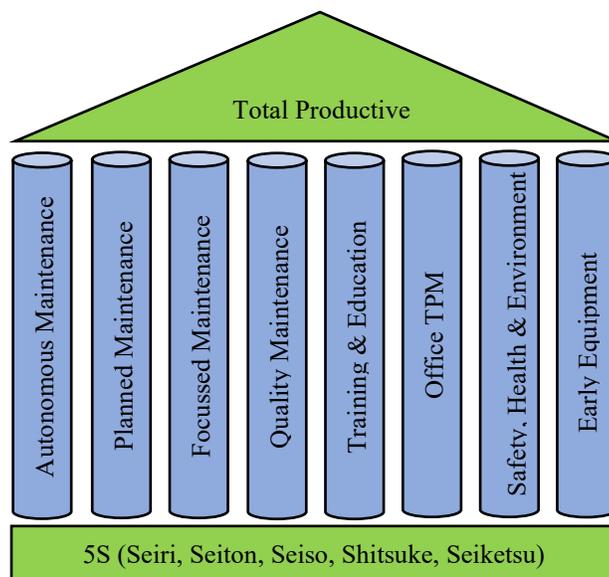


Figure 2. The Pillar of Total Productive Maintenance
Source: (Nakajima, 1988)

3. Methods

To increase the overall effectiveness of the machine, to increase productivity, the Total Productive Maintenance method is used with OEE measurement as a parameter. This research is quantitative.

The following are the data needed in this study, namely as follows:

- (1) the number of working hours and working days available and determined by the company;
- (2) the amount of downtime planned by the company, such as the length of time off, scheduled maintenance meetings and so on
- (3) the amount of downtime that is not planned by the company due to several things such as engine repairs, machine adjustments, production failures etc
- (4) long and minor idle and silent stopping equipment
- (5) the ideal cycle time and the actual condition cycle time
- (6) the total number of parts produced
- (7) the total number of defective products and rework
- (8) history of both preventive and corrective machine maintenance

4. Results and Discussion

In the Musical Instrument Industry, the TPM strategy is applied sustainably on each of its pillars. The success parameter of this TPM strategy is OEE. The value of OEE has become a company standard, as a success towards a world-class company. This study, only discussing some of the pillars of TPM including 5S, Autonomous Maintenance,

Focused Maintenance, Planned Maintenance, Each pillar implementation of TPM will be discussed in the following subsections:

4.1. 5 S (Seiri, Seiton, Seiso, Shitsuke, Seiketsu)

The TPM implementation strategy starts with 5S. 5S is the basic foundation in implementing TPM. The aim of 5S in TPM is to create a clean and healthy work environment. The approach used is as follows:

1. Seiri (clearing up): Separating some tools on NC Bore machines that are still used and not used, such as router bits and bore eyes. Then remove unnecessary, so that the placement of the tools is neat.
2. Seiton (organizing): Arranging several tools in NC Bore machines such as jigs, router bits, router eyes, adjustment keys, mats etc. Place it on the shelf with the identity. So that when it is used it is easy to sort and retrieve.
3. Seiso (cleaning): Cleans the table area on the NC Bore Machine after each end of working with a vacuum cleaner. Cleaning is also carried out on the racks where the tools and jigs are located.
4. Seikatsu (standardizing): Creating standards for cleanliness, lubrication and inspection in a control. To ensure this activity, the leadership conducted a 5S audit
5. Shitsuke (training and discipline): Improve the skills and morale of employees' personal habits by providing regular 5S training to operators. So that with training, the operator's awareness of cleanliness will continue to increase.

4.2. Autonomous Maintenance

This pillar is machine maintenance that involves production operators as users to perform basic maintenance. The implementation of this pillar aims to increase the knowledge, skills and responsibilities of production operators related to machines so that overall productivity will increase. This maintenance is the basis for other maintenance. Various maintenance standards are applied from cleaning, inspection and lubrication. Cleaning standards on NC Bore machines are given in Table 1. Other maintenance standards are inspection standards on machines described in Table 2 and lubrication standards for engine components described in Table 3.

Table 1. Cleaning Standards

No	Item cleaning	Equipment	Frequency
1	Machine table	Vacuum cleaner	Daily
2	Motor servo	Vacuum cleaner	Weekly
3	Shaft Spindel	Dry cloth	Weekly
4	Hydraulic tank outside	Dry cloth	Weekly
5	Monitor screen	Dry cloth	Weekly

Table 2. Inspection Standards

No	Item Inspections	Standard	Frequency	Action Taken
1	Oil regulator	Max and Min	Weekly	Fill up oil
2	Motor servo	Sound is not harsh	Daily	Repair
3	Vacuum pump	There is no leak	Daily	Repair
4	Shaft Spindel	Up and down smoothly	Daily	Cleaning of the shaft
5	Emergency switch	Works fine	Daily	Repair
6	Fanbelt	Don't crack	Weekly	Spare part replacement

Table 3. Lubrication Standards

No	Item Lubrication	Method of Lubrication	Type of Lubrication	Frequency
1	Ball Bearing	Manual	Oil	Monthly
2	Regulator for spindell	Otomatis	Oil	Weekly
3	LM Gate (nipple)	Manual	Grease	Monthly

4.3. Planned Maintenance

In this pillar namely, the implementation of organized maintenance and carried out with thoughts towards the future. The purpose of this pillar is to anticipate machine failure by using three methods, namely preventive maintenance, corrective maintenance and predictive maintenance. Some of the approaches taken include:

1. Perform preventive maintenance, namely the planned and periodic maintenance scheduling of NC Bore machines, both weekly and monthly. One of the actions taken is the monthly replacement of spare parts, in anticipation of a sudden abnormal component.
2. Adding the preventive maintenance schedule from 4 times a year to 6 times a year.
3. Order spare parts according to the limit order, so that the spare parts are ready to use if needed. This prevents long machine breakdowns that result in production stops.
4. Perform corrective maintenance on machines that have unexpected damage. This explanation is described in Table. 4

Table 4. Abnormalities in the Machine NC Bore

No.	Abnormalities	Effects	Cause	Action
1	The piston pipe is corroded so that the spindle movement is not smooth	The spindle shaft cannot go up after going down	There is a gap in the spindle shaft head	Making acrylic and rubber covers to reduce gaps in the spindle head shaft so that the incoming dust is reduced
2	The stopper broke and bent	The stopper is not precise	Spindle movement hit stopper (wrong program)	Repair stopper, do trial and simulation first
3	The vacuum blade is running low	The ORION KRF vacuum motor sounds harsh	The service life of the machine is old	Vacuum motor blade replacement
4	Rubber vacuum pad dirty and peeled off	Vacuum strength is not optimal	The dust that enters during the process through the cracks and is not regularly cleaned	Periodic cleanup and replacement of the vacuum pad rubber
5	The air hose on the oil regulator is leaking	There is no lubrication on the spindle shaft	The air hose on the oil regulator is worn	Oil regulator replacement

5. Perform predictive maintenance, which is to detect abnormalities early on NC Bore machines by installing sensors on important parts of NC Bore machines. The sensor that is installed is intended to detect abnormal conditions such as high temperature, vibration, program error etc. This is following the concept of industry 4.0, predictive maintenance needs to be redefined to suit the modern manufacturing world. Industry 4.0 is based on cyber-physical systems and the digitization of information, facilitating the accumulation and transformation of real-time information processing into decisions to reduce uncertainty in outcomes. Industry 4.0 is characterized by the role of the IoT. In fact, in improving engine performance, a sensor is needed. The implementation of this sensor is to detect abnormalities such as vibrations, temperature, running program errors and others. This sensor will transfer normal conditions to the cloud via IoT. This sensor can inform about abnormalities in real-time. If there is excessive vibration or high temperature, it means that the machine will breakdown. Then we can have a quick response to prevent a breakdown in the middle of production. If a breakdown occurs during production, it will hurt the company. The losses include operators stopping work, defective goods, stop lines during production hazards and others. With this, the importance of the role of IoT

in its implementation in improving machine performance. Figure 3 is the machine learning cycle in industry 4.0

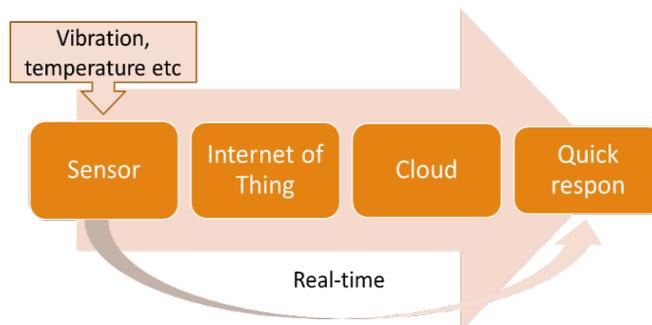


Figure 3. Machine Learning cycle in industry 4.0

4.4. Focussed Improvement

This pillar can also be called Kaizen, which is continuous improvement. Improvement towards it is better done by involving many people from all levels of the organization. This pillar aims to reduce losses in the workplace that affect productivity and efficiency. The approaches used in this pillar include:

1. Make a cover on the spindle shaft to prevent dust from entering. The effect is to reduce abnormalities such as not smooth moving up and down the spindle shaft.
2. Install the indicator light on the oil regulator, so that if the oil runs out it will be detected on the indicator light. This prevents abnormal spindle motion

4.5. Quality Maintenance

The Quality Maintenance pillar addresses quality problems by ensuring production equipment or machines can detect and prevent errors during production. This is geared towards achieving customer satisfaction through the delivery of the highest quality products. The approaches taken include:

1. Sizing the machine stopper every week. This is intended to detect abnormalities in the X, Y and Z axis dimensions on the machine.
2. Implement early error detection (Poka Yoke, Mistake Proofing)

4.6. Training and Education

This Training and Education pillar is intended to address gaps/shortages in operator knowledge and skills when implementing maintenance strategies. Lack of knowledge of the tools or machines it uses will create damage to the equipment and lead to low work productivity which ultimately harms the company. The approaches taken include:

1. Provide knowledge training related to maintenance and care for operators. Training is given to the NC Bore operators and the maintenance team. This training is carried out by an internal company.
2. Skills improvement for the maintenance team to be competent in carrying out engine repairs. Training is carried out externally to the company providing maintenance skills improvement service providers

4.7. HSE (Health, Safety and Environment)

This pillar aims to create a workplace that is healthy, safe and comfortable so that it will affect the zero accidents caused by the work process. Many improvements have been made to achieve zero accidents, this is following the company's action plan. Some of the approaches taken include:

1. Install sensors on the front of the machine, so that if the operator moves into a dangerous area, the machine will stop for a moment.
2. Installation of the cover on the spindle shaft so that the remaining material from the mental process will not hit the operator. This will prevent work accidents.
3. Adding an indicator light to the remaining rotation of the router, which functions as a safety sign for the operator when changing materials.

4.8. Calculating the OEE value

In the Musical Instrument Industry, especially in the Wood Working process, NC Bore Machines work eight hours per day and five days a week. Data when the NC Bore machine works were collected, the rest is shown in Table 5.

Table 5. Data running machine NC Bore

Type of Data	Time	
	Before	After
Number of working days in a month	20 days	20 days
Total time of day	540 min	540 min
Operating time	480 min	480 min
Set-up time per day	23 min	23 min
Setup time per month	460 min	460 min
Break time per day	60 min	60 min
Breakdown time per month	612 min	102 min
Unplanned downtime per month	1072 min	582 min
Preventive maintenance per year	4 times	6 times
Idle run time	1,06 part/min	1,12 part/min
Total produced parts per month	7106 pcs	7531 pcs
Defect goods per month	292 pcs	81 pcs
Number of good products per month	6814 pcs	7450 pcs

It should be noted that the parameter of the successful implementation of the TPM strategy is the OEE value. OEE is nothing but a comparison of the effectiveness of a machine with the ability of an ideal engine to produce. In practice, OEE is calculated as a product of availability, performance and quality as follows.

- Before the implementation of TPM

The following is the calculation of the value of Availability, performance, quality level and OEE on NC Bore machines before the implementation of TPM is calculated as follows:

$$\text{Availability} = (9600-1072) / 9.600 \times 100\% = 89\%$$

$$\text{Performance} = (1.06 \times 7106) / 8528 \times 100\% = 88\%$$

$$\text{Quality Rate} = (7106-182) / 7106 \times 100\% = 97\%$$

$$\text{OEE} = 89\% \times 88\% \times 97\% = 76\%$$

- After the implementation of TPM

The following is the calculation of the value of availability, performance, quality level and OEE on NC Bore machines after the implementation of TPM is calculated as follows:

$$\text{Availability} = (9600 - 582) / 9600 \times 100\% = 94\%$$

$$\text{Performance} = (1.12 \times 7531) / 9038 \times 100\% = 93\%$$

$$\text{Quality Rate} = (7531 - 82) / 7531 \times 100\% = 99\%$$

$$\text{OEE} = 94\% \times 93\% \times 99\% = 87\%$$

Figure 4 shows the comparison of OEE values before and after the implementation of TPM in NC Bore machines. It can be concluded that the current OEE value is at the world class level.

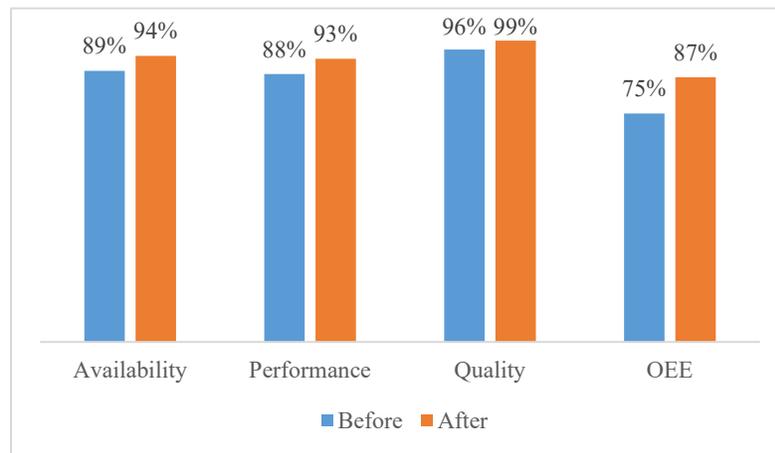


Figure 4. OEE Value Before and After the Implementation of TPM

5. Conclusions

Based on the results and discussion in the previous sub-section, it is known that to achieve the goals in the TPM strategy, many approaches are used. Some of the approaches taken include the implementation of 5S, education and training for operators, manualization of machine operations, application of sensors on machines as early detection of breakdown, this is in line with the implementation of industry 4.0 characteristics. Based on the above results, the following conclusions are drawn.

The OEE value on the NC Bore machine increased from 75% to 87% or increased by 12%. Thus the OEE value on the NC Bore Machine meets world-class standards.

- Availability of NC Bore Machines increased from 89% to 94%
- Performance on NC Bore Machines increased from 88% to 93%
- Quality on NC Bore machines increased from 96% to 99%
- Based on the defect rate, the quality of NC Bore machines increased by 3%

6. Suggestion

This research has several limitations, including that there has not been an overall analysis of the TPM pillars. The implementation of this TPM was not carried out along with a cost analysis. In future research, it can be expanded by discussing all the pillars of TPM and discussing aspects of maintenance costs, so that the company will know how much cost savings the company receives.

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Biography

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